DAY ONE PROJECT

Integrating Automated Vehicles with 5G Networks to Realize the Future of Transportation

Brian Kelley
Kara Kockelman
Junmin Wang

June 2021

Summary

Widespread deployment of fully automated or "autonomous" vehicles (AVs) that can operate without human interaction would make travel easier, cheaper, and safer. Reaching this highest level of automation requires AVs to be connected to 5G networks, which in turn allows AVs to communicate with "smart", 5G-connected roadway infrastructure. The federal government can support progress towards this goal through a three-part initiative. Part 1 would establish Transportation Infrastructure Pilot Zones to field-test the integration of AV technology with 5G networks in settings across the country. Part 2 would create a National Connected AV Research Consortium to pursue connected-vehicle research achieving massive scale. Part 3 would launch a targeted research initiative focused on ensuring safety in a connected AV era, and Part 4 would create a new U.S. Corps of Engineers and Computer Scientists for Technology to embed technically skilled experts into government. With primary support from the National Highway and Traffic Safety Administration (NHTSA), the National Science Foundation (NSF), and the Department of Defense (DOD), this initiative would also help develop a basic framework for achieving a 90% reduction in vehicle crashes nationwide, deliver new transportation services, and establish national standards for AV technology. Initiative outcomes would promote U.S. global leadership in AVs, create new jobs and economic opportunities, and prepare the U.S. workforce to integrate technology of the future into systems of the present.

Challenge and Opportunity

The U.S. Interstate Highway System has remained relatively stagnant since being established under President Eisenhower. But the advent of new AV technology promises to revolutionize road transportation in the near future. At the highest levels of automation, as defined by the U.S. National Highway and Traffic Safety Administration (NHTSA), vehicles can "[complete] all duties without a driver on all roads in all conditions."[1] Just as artificial intelligence (AI) enables computers to easily defeat human grandmasters at chess, future vehicles will contain AI-driven sensors that will enable vehicles to easily drive more safely and efficiently than humans.

Figure 1. Rendering of a 5G network tower communicating with 5G-network connected, autonomous vehicles.

[1] Ondruš, J.; et al. (2020). How Do Autonomous Cars Work? *Transportation Research Procedia*, 44:, 226–233.

Realizing the Future: Connecting AVs with 5G

Achieving ultra-safe autonomous road transportation at scale requires integration of AV technology with 5G networks.[2,3] 5G-connected AVs can communicate with each other and with 5G-connected road infrastructure (Figure 1). Such vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication enables AV services such as coordinated route planning, reduction of traffic congestion, collision prevention, affordable public transportation, on-demand chauffeuring for commuters, detection of irregular vehicle operation, and improvements in general road safety.

Practical applications of large-scale AV services are myriad. For instance, connected cars that get into an accident could automatically alert the closest certified medics. Employees could work "in-vehicle" while being chauffeured to work by 5G-hosted AV systems, reclaiming productivity currently lost while commuting. Affordable fleets of AVs could make it easier for elderly and disabled patrons to get to medical appointments and stores without having to rely on someone for a ride. Flexible, 5G-enabled congestion pricing coupled with coordinated route planning could significantly reduce traffic congestion. Indeed, IDTechEx Research[4] found that new transportation services could present a $2.5 trillion global revenue opportunity by 2040.

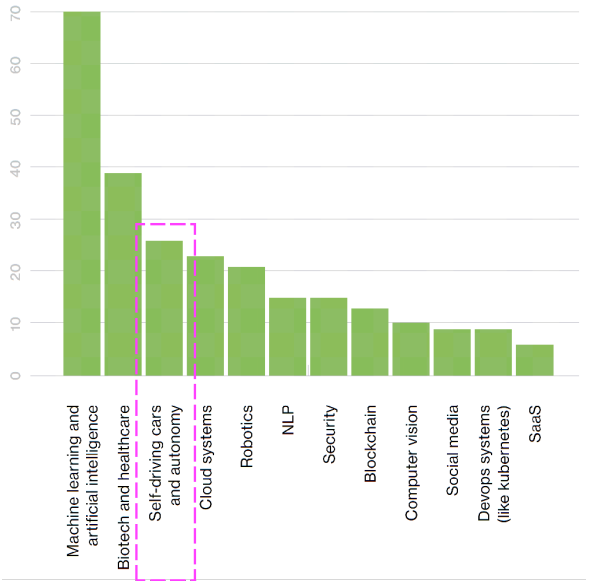

Figure 2: 2020 survey of North American engineers on technologies capable of reshaping society.

The race is already on to deploy such vehicles. China's "Belt and Road Initiative" has spent $237 billion over the last five years building out 5G networks in Europe and China.[5] This effort includes laying roadway fiber optics for 5G AV networks and reallocating 200 MHz of spectrum for 5G internet applications and 5G services. The H2020 Large Scale Trials project known as "5G-Drive"—a collaboration between Finland, Italy, the United Kingdom, and China—is actively shaping 5G vehicle standards. The stakes are high. Emergen Research estimates the AV market to reach $724 billion by 2027[6]. Respondents to a 2020 survey of North American engineers named self-driving cars and vehicle autonomy as technologies with some of the greatest potential to reshape

[2] Molinaro, A.; et al. (2020). 5G-V2X Communications and Networking for Connected and Autonomous Vehicles. *Future Internet*, 12(7): 116..

[3] Storck, C.; Duarte-Figueiredo, F. (2019) A 5G V2X Ecosystem Providing Internet of Vehicles. *Sensors*, 19(3): 550.

[4] Jiao, N. (2019). Latest IDTechEx Research on Autonomous Cars and Robotaxis 2020-2040. IDTechEx, November 8.

[5] Kostopoulos, A.; et al. (2019). 5G Trial Cooperation Between EU and China. In: *2019 IEEE International Conference on Communications Workshops (ICC Workshops)*. Shanghai, China: 1–6.

[6] Emergen Research. (2020). Autonomous Vehicle Market By Component (Camera, LiDAR, Radar, Ultrasonic Sensor), By Application (Civil, Robo taxi, Ride hail and share, Self-driving Bus and Truck (and By Fuel Type (ICE, HEV, BEV) Forecasts to 2027.

society. Without ambitious action to massively scale up 5G-connected AVs on U.S. roadways, the United States risks being left behind.

Plan of Action

The federal government should launch a national initiative to pave the way for an AV-enabled transportation revolution in the United States. This effort would comprise four parts:

- Part 1: Establish Transportation Infrastructure Pilot Zones, experimental sites to field-test integration of AV technology with 5G networks in settings across the country.
- Part 2: Create a National Connected AV Research Consortium to pursue connected-vehicle research achieving massive scale.
- Part 3: Launch a targeted research initiative focused on ensuring safety in a connected AV era.
- Part 4: Create a new U.S. Corps of Engineers and Computer Scientists for Technology to embed technically skilled experts into government programs related to AV deployment and 5G connectivity.

Part 1. Establish Transportation Infrastructure Pilot Zones

The NSF, NHTSA, and DOD should administer a $790M program to fund field tests of 5G-enabled AV infrastructure. This program would designate sites across the country as Transportation Infrastructure Pilot Zones. Table 1 lists sites that could be good initial locations for these Zones because they already (i) host significant AV pilots, (ii) have 5G infrastructure suitable for connected-vehiicle technology, and/or (iii) demonstrate strong relationships between local stakeholders and transportation agencies. These sites include private, public, and military-base roadways and highways, illustrating the wide diversity of locations that could serve Pilot Zones. Leveraging areas where partially connected vehicle infrastructure already exists is the most efficient way to quickly advance roadway connectivity. Placing 5G computing, networking, and wireless infrastructure in road proximity enables seamless 5G-network control (i.e., V2X edge computing), with 5G-connected AVs liniking the wireless infrastructure covering the roadway.[7] Institutions—including large private companies, small businesses, research institutes, municipalities, and non-governmental organizations—could propose test projects to be hosted

[7] Raissi, F.; Yangui, S.; Camps, F. (2019). Autonomous Cars, 5G Mobile Networks and Smart Cities: Beyond the Hype. In: *2019 IEEE 28th International Conference on Enabling Technologies: Infrastructure for Collaborative Enterprises (WETICE)*. Napoli, Italy: 180–185.

Table 1: Proposed sites for Transportation Infrastructure Pilot Zones

Category	Govt. Organiz.	Infrastructure Zones and Existing Pilots Justifying Selection	
Highway	NHTSA, FDOT	Connected and Automated Vehicle (CAV) efforts	Interstate 75, FL
Highway	NHTSA, Caltran	San Diego Reg. Proving Grounds (SDRPG) efforts	I-805, CA Route 52
Military Base	DoD, OUSD R&E	5G Core Security Experimental Site at Joint Base SA	San Antonio, TX
Private Road	NHTSA, State of MI	Multiple 5G AV test environ. (AACVTE, MCity, ACM)	Ann Arbor, MI
Private Road	NHTSA, TxDOT	JJ Pickle Research roadway and Autonomy Institute	UT Austin, TX
Roadway	NHTSA, Caltrans	California Department of Transportation 5G tests	Chula Vista, CA
Roadway	NHTSA, NSF, NYCDOT	Danlaw's 5G Solution, Connected Vehicle Project, NSF	New York, NY
Roadway	NHTSA, VDOT	Smart Road Corridor focused on 5G Connected vehicles	Virginia Tech, VA

at these sites. In the future, additional funding could be allocated to help scale technologies and capabilities proven successful in these pilots (e.g., to first 1% and ultimately 75% of the country[8]).

Part 2. Create a National Connected AV Research Consortium to pursue connected-vehicle research achieving massive scale

A National Connected AV Research Consortium would advance crucial research efforts involving 5G-connected vehicular communication protocols. Through an $80 million grant program administered jointly by the NHTSA, NSF, and DOD, the Consortium would support research and development projects at pilot sites (i.e., the Transportation Infrastructure Pilot Zones) as well as research into topics such as new 5G-network services; innovative, AV-enabled delivery of public transportation; massive scaling of AVs; and strategies for reducing congestion through a combination of connected route planning, congestion pricing,[9] and smart transportation services. Funded research would study integration of AV technology and 5G connectivity for multiple vehicle classes, including passenger vehicles, small public vehicles, and long-haul light trucks.

Part 3: Launch a targeted research initiative focused on ensuring safety in a connected AV era

Maximizing AV safety requires the presence of redundant safety mechanisms onboard AVs as well as the capacity for human drivers to take control of AVs via the 5G network in the event of complex emergencies. Technology to thwart ransomware, cyberattacks, and data breaches is needed to ensure cybersecurity. Finally, assigning vehicle control to multiple independent

[8] Medin, M.; Louie, G. (2019). *The 5G Ecosystem: Risks & Opportunities for DoD*. Defense Innovation Board.
[9] Simoni, M.D.; et al. (2019). Congestion pricing in a world of self-driving vehicles: An analysis of different strategies in alternative future scenarios. *Transportation Research Part C: Emerging Technologies*, 98: 167–185.

systems within an AV ensures resilient operation. Dispersing control across multiple systems eliminates the possibility that an AV could become compromised by a single failure point.

NSF should lead a $70 million effort to fund research focused on advanced safety, cybersecurity, and resilient control systems for critical infrastructure networks operating at a national scale—including networks of 5G-connected AVs and road infrastructure. As part of this effort, the NSF and DOD would initiate academic partnerships among universities, research institutes, community colleges, and federal research labs to develop innovative roadway infrastructure technology that allows for massive network control of AVs without data breaches and cybersecurity controls. Finally, the effort would fund complementary research into new insurance models for AVs,[10] AI ethics in an AV context, and the economics for safe and secure AV systems.

Part 4: Create a new U.S. Corps of Engineers and Computer Scientists for Technology

With $60 million in funding, the Department of Commerce (DOC) and the U.S. Army Corps of Engineers (USACE) can jointly establish training, education, and professional development programs in engineering. Strengthening the country's pipeline of commercial engineers, commercial researchers, government researchers, and technologists would fill the talent gap in areas where the United States lags or has industrial supply-chain vulnerabilities. These areas include network-connected AVs, 5G (and beyond) networks, network cybersecurity, and AI technology. Part of the $60 million should be dedicated to launching a new U.S. Corps of Engineers and Computer Scientists for Technology (CECST). The CECST would embed technically skilled experts in federal programs and offices related to network-connected infrastructure or other supply-chain technologies involving extensive U.S. infrastructure and capital investment. The DOC and the USACE should also coordinate with each other and other federal agencies on policies that promote commercial business enterprises for intelligent infrastructure and other crucial needs. Training an intelligent transportation labor force in smart infrastructure jobs of the future will improve the technology talent pipeline for small businesses and U.S. industry.

Conclusion

Highly automated AV technology has the potential to transform society by dramatically accelerating the delivery of goods, slashing the environmental footprint of road transportation, making travel exponentially safer, and more. Realizing these benefits on a massive, nationwide scale will require close integration of AVs with advanced 5G network concepts not typically associated with transportation. The federal government should launch a four-part initiative designed to facilitate such integration. By establishing experimental pilot zones to road-test 5G-connected vehicles and road infrastructure; funding research into the development, safety, and cybersecurity of highly automated and connected AVs; and conducting large-scale training to

[10] Bojic, I.; Braendli, R.; Ratti, C. (2019). What will autonomous cars do to the insurance companies? In: *Autonomous Vehicles and Future Mobility*, Elsevier: 69–84.

prepare Americans to participate in the AV economy, this initiative will ensure that the United States remains a global leader in transportation and connectivity—and is well prepared to embrace the forthcoming revolution of the road.

Frequently Asked Questions

Which federal agencies will be responsible for carrying out different aspects of this initiative?

The NSF, NHTSA, and DOD will designate the sites for Transportation Infrastructure Pilot Zones and will administer funding for experimental projects carried out within these zones. These three agencies will also facilitate research partnerships with external stakeholders through the National Connected AV Research Consortium. The NSF will administer a complementary research program focused on safety, cybersecurity, and resilience of 5G-connected AVs. DOC and the USACE will oversee a national training program designed to prepare Americans to participate in the AV economy, as well as the launch of a new U.S. Corps of Engineers and Computer Scientists for Technology that will embed technically skilled experts in federal offices and programs to help shore up U.S. capacity in key strategic technological domains, including highly automated and connected AVs. We note that regulation and rulemaking around 5G-connected AVs will also be essential as research and technical capacity advances. The NHTSA (which already develops incentives for insurance coverage of AVs, congestion-pricing standards, and insurance simplification) should lead development of such policies, with input from other federal agencies as appropriate.

How much would it cost to massively scale 5G-connected AV technology in the United States?

In the immediate future, funding is most needed for critical research, development, and pilot projects to field-test highly automated and connected vehicles and road infrastructure. Funding is also needed to build out 5G connectivity in Pilot Zones and across adjacent transportation infrastructure (e.g., nearby highways and roads). We estimate that a total of $1 billion would be needed to accomplish these goals.

Moving forward, additional investment will be needed to scale up technologies proven successful in Pilot Zones, and to build out 5G networks to cover more and more of U.S. road infrastructure. We estimate that $6 billion would be needed to scale up AV technologies and 5G networks to enable 5G-connected AV operation on 1% of the U.S. road-transportation network. Assuming that economies of scale reduce expansion costs by ~50% over five years, we estimate that $200 billion would be need to further scale AV and 5G to reach 75% of the U.S. road-transportation network.[11] These costs are eminently reasonable when compared with the substantial market opportunities that AVs are projected to create. Market analysis suggests that the global annual revenue of AVs will be $724 billion by 2027, and $2.04 trillion by 2030, and $7 trillion by 2050. These estimates are before even factoring in the economic value of deaths

[11] This estimate is based on a report from the Defense Innovation Board, which found that the United States would need to spend $400 billion (in 2019 dollars) to deliver a 100 Mbps edge rate at 28 GHz to 72% of the U.S. population. The cost of coverage across the entire country should decline significantly over time as economies of scale increase. Source: Medin, M.; Louie, G. (2019). *The 5G Ecosystem.*

and injuries avoided by improved road safety—widespread deployment of AVs could conceivably reduce vehicle crashes by 90%.[12]

How exactly do you envision this initiative unfolding?

During the research and development phase, the NHTSA, NSF, and DOD would jointly support field-testing of 5G-connected AVs and road infrastructure on approved public roads, military bases, private facilities, and university sites (i.e., the Transportation Infrastructure Pilot Zones). These agencies would also fund development of safety and cybersecurity proposals, and would help establish of relevant standards. Moving forward, the Pilot Zones would serve as National Centers of Excellence to support scale-up and roll-out of connected AV technology across more of the country. The NHTSA, NSF, and DOD would facilitate public-private partnerships to spur growth of commercial industry, promote a favorable regulatory landscape, and create appropriate incentives to help realize a road-transportation future built on entirely autonomous, 5G-connected vehicle technology. Ultimately, the NHTSA would provide large grants to expand 5G road connectivity to at least 75% of the United States, including interstate highways as well as road networks within and around urban areas. Grants would be awarded through a competitive-bid process to private contractors.

How do we solve the "chicken or egg" (vehicles vs. infrastructure) problem of massive-scale deployment of 5G-connected AVs?

The federal grants proposed in this memo focus on a building out 5G-enabled road infrastructure. Once this infrastructure exists, private companies will have a natural incentive to get network-connected AVs on the road. The federal government can expedite this process by implementing additional incentives, such as rebates for AV R&D, tax rebates at the point of sale for 5G-connecte AVs, and limits on manufacturer's product liability. Finally, the federal grants will also support research into re-architecting cars to connect to 5G. This will help quickly grow the fleet of vehicles able to take advantage of the benefits that 5G-connected road infrastructure can offer.

What is the current status of highly automated vehicle technology?

Zoox, Waymo (a Google subsidiary), and some other companies are already experimenting with vehicles at the highest level of automation (NHTSA Level 5). Tesla's market-ready vehicles are equipped with technology that provides close to Level 5 automation. Other examples of highly automated vehicles in practice include:

- Keolis and NAVYA (2017), in partnership with the city of Las Vegas, launched the first autonomous, fully electric shuttle to be deployed on a public roadway in the United States.

[12] Lanctot, R. (2017). Accelerating the Future: The Economic Impact of the Emerging Passenger Economy. *Strategy Analytics*, 1–30.

- Toyota (2018) announced its 'e-Palette' concept vehicle, which is a fully electric AV that can be customized by a partner for applications such as food deliveries (Pizza Hut), ride-sharing (Uber), or storefronts (Amazon).
- Udelv (2018), a Bay Area tech company, completed the first delivery of goods by a self-driving car when it delivered groceries in San Mateo.
- Hyundai (2018) announced that a fleet of its fuel-cell electric cars made an entirely successful automated trip from Seoul to Pyeongchang.

As the autonomous capabilities of individual vehicles increase and vehicles with these capabilities make it onto roads, deployment of 5G network control is increasingly important to ensure transportation safety, congestion control, route planning, and resilience.

What role does this initiative envision for the U.S. Department of Transportation (DOT)?

The DOT should continue to promote a positive regulatory environment, standards, and transparency around automated vehicles.[13] DOT should also continue to support critical research into AV-relevant technologies, including AI and machine learning, computer vision, sensing, radar, LIDAR, safety, sensor fusion, spectrum research, V2V and V2I, highway R&D, and intelligent transportation systems.

What does the United States risk if the proposals in this memo are not implemented?

As of 2020, no U.S. company is in the top three in AV patents. Without federal intervention to bolster U.S. leadership and capabilities in 5G and AV technology, the following could occur:

- U.S. auto manufacturers lower R&D spending on AVs given an unfriendly regulatory and innovation environment.
- Private investment in worker training for technologies of the future lessens.
- U.S. commercial technology in unmanned vehicles decreases, and the United States loses a potential first-mover advantage in the $2 trillion/year (projected by 2030) AV market.
- Absence of new AV services capable of multiplying U.S. economic competitiveness slows domestic economic growth.
- Foreign telecommunications companies dominate the competitive 5G connected-vehicle marketplace.
- Foreign companies dictate the global 5G standards that will ultimately shape the connected-AV landscape.

[13] U.S. Department of Transportation. (2021). *Automated Vehicles Comprehensive Plan.*

What detail does this proposal add to the conversation around AVs?

Many are aware that development of AVs is underway, and much has been written about the transformative potential of AV technology. Far less attention has been paid to the importance of integrating AV technology with 5G connectivity. The ability of 5G networks to access gigantic computing and storage capability in the cloud (i.e., the 5G core network) allows efficient economies of scale when it comes to AV operation, thereby improving AV safety, scalability, routing, and control. 5G networks can also host many AI, machine-learning, and security applications needed by AVs. Agencies with leadership in 5G technology and standards include DOC, DOD, DOT, and NSF. This proposal presents an integrated vision for how these agencies can work with the NHTSA and other stakeholders to realize a road-transportation future build on and around massive deployment of 5G-connected AVs.

About the Authors

Dr. Brian Kelley, Associate Professor in Electrical and Computer Engineering, joined the University of Texas at San Antonio (UTSA) in 2007. He received a bachelor's degree in electrical engineering from Cornell University, graduating Tau Beta Pi and Eta Kappa Nu, and a master's degree and Ph.D. in electrical engineering from Georgia Tech. Dr. Kelley holds 11 U.S. patents, has authored over 60 publications, was previously Associate Editor of the IEEE System Journal, and has received over $3 million in funding for his research. Dr. Kelley's current research includes 5G/6G, mobile edge computing, autonomous vehicle infrastructure, artificial intelligence, and security. Dr. Kelley has been the 5G Principal Investigator in 5G Core Security and 5G Telemedicine since 2020 with Joint Base San Antonio's Program Management Office (PMO).

Dr. Kara Kockelman is the Dewitt C. Greer Professor of Engineering at UT Austin and is a recognized expert on autonomous vehicle (AV) use, shared AV systems, travel demand forecasting, traffic patterns under congestion pricing, and managed lanes and economic policies. Her current research projects include focuses on travel demand, economic, traffic, safety, and other impacts of connected and autonomous vehicles. Dr. Kockelman received the MIT Top 100 (Young) Innovators Award (2002), an NSF CAREER Award (2000–2004), the ASCE's Harland Bartholomew Award for transportation planning contributions (2007), and a Google Research Award (2014) for her travel-demand modeling work on autonomous vehicles. Dr. Kockelman received a bachelor's degree, master's degree, and Ph.D. from UC Berkeley.

Dr. Junmin Wang has been the Accenture Endowed Professor in Mechanical Engineering at University of Texas at Austin since August 2018. Dr. Wang's research interests cover control, modeling, estimation, optimization, and diagnosis of dynamical systems, especially for automotive, vehicle, transportation, smart and sustainable mobility applications. Prof. Wang's research programs have been funded by the National Science Foundation, the Office of Naval Research, the Department of Energy, the National Highway Traffic Safety Administration, and the Texas Department of Transportation. Dr. Wang has authored or co-authored more than 330 peer-reviewed publications. Dr. Wang was named an SAE Fellow (2015) and an ASME Fellow (2016). He serves

as Editor for the IEEE Vehicular Technology Magazine and IEEE Transactions on Vehicular Technology.

About the Day One Project

The Day One Project is dedicated to democratizing the policymaking process by working with new and expert voices across the science and technology community to develop actionable policies that can improve the lives of all Americans. For more about the Day One Project, visit dayoneproject.org